The Advanced Scintillator Compton Telescope (ASCOT) Balloon Project

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Philosophy

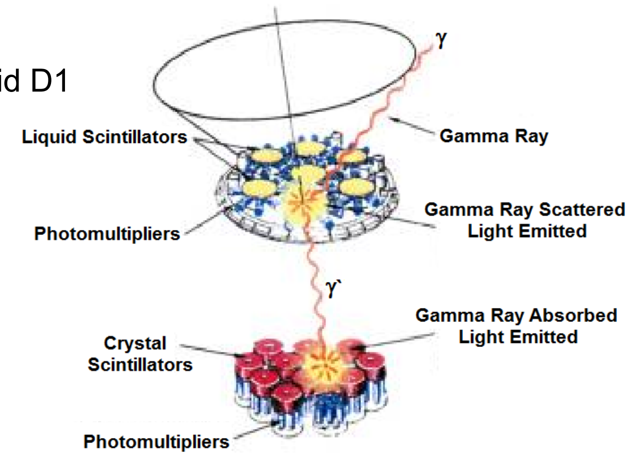
- The ASCOT project is motivated by the theory that the most cost-effective, low-risk way to implement an advanced, ***general-purpose*** Compton telescope is to build directly on the experience of COMPTEL
- A advanced, scintillator-based Compton telescope would use ***modern detector materials*** to improve efficiency, energy resolution, and time-of-flight (ToF) resolution for background rejection
- It would also use ***advanced light readout devices***, such as silicon photomultipliers (SiPMs), to reduce passive mass, volume, and power

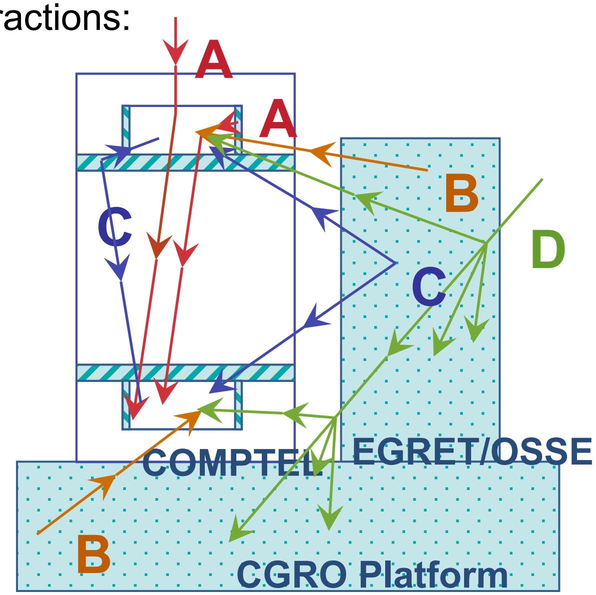
COMPTEL Background

COMPTEL suffered intense background from particle interactions:

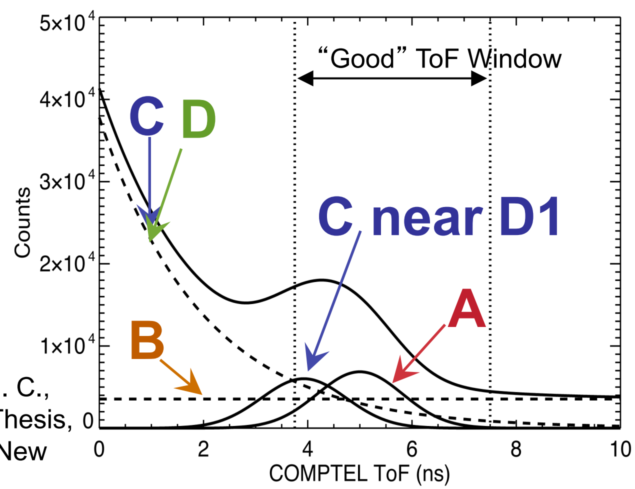
Organic Liquid D1

NaI D2

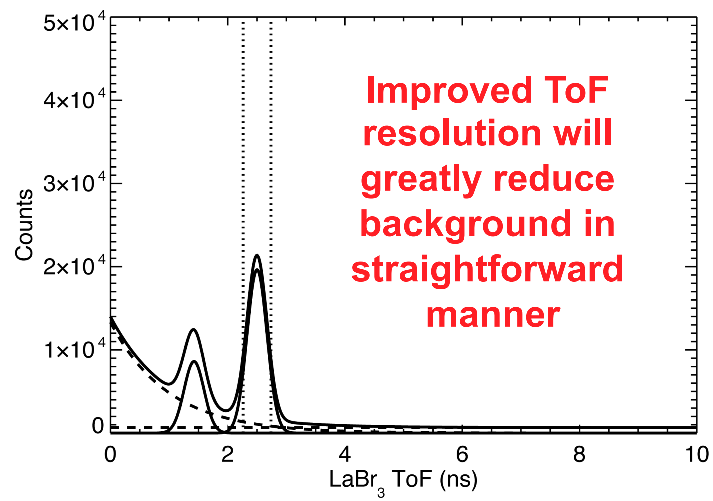




ToF was critical to COMPTEL's sensitivity:



Kappadath, S. C., 1998, Ph.D. Thesis, University of New Hampshire



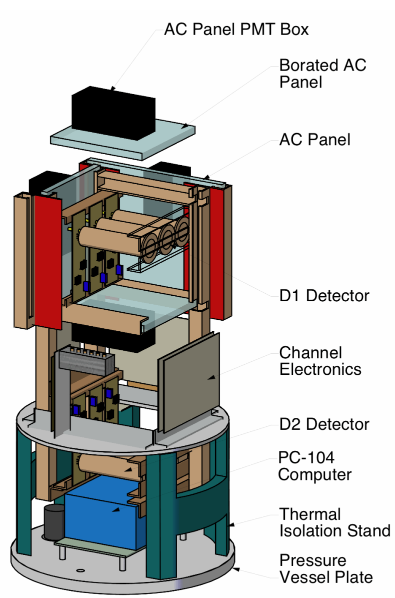
Balloon Flight Demonstrations

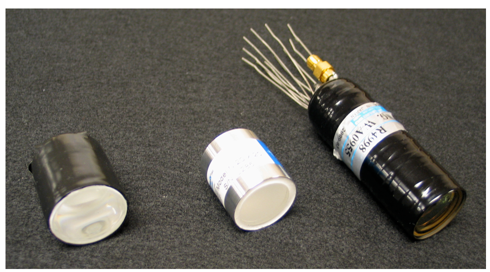
UNH has conducted two successful balloon flight tests of available technology that would enable an advanced scintillator Compton telescope:

- The **FAst Compton TELescope (FACTEL)** experiment (September 2011): new scintillators (collaboration with LANL)
- The **Solar Compton Telescope (SolCompT)** experiment (August 2014): SiPM readouts

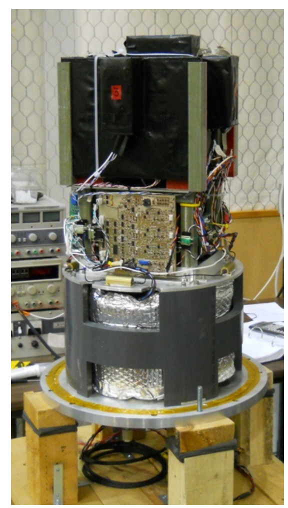
FACTEL Experiment

- Compton telescope consisting of three 1-inch liquid organic D1 scintillators and three 1-inch $LaBr_3$ D2 scintillators, all read out by fast PMTs
- D1-D2 separation of ~30 cm
- D1 surrounded by plastic ACS
- Pressure vessel, PC-104 flight computer



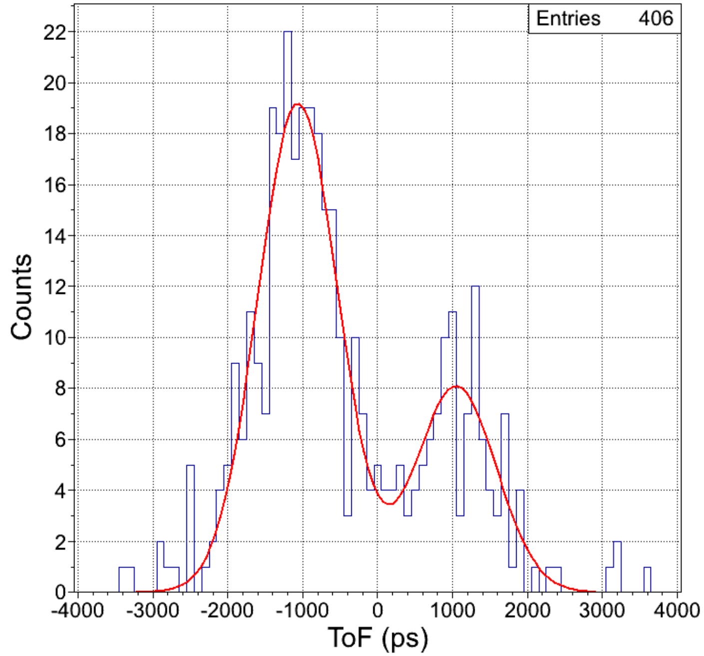


Liquid $LaBr_3$ PMT

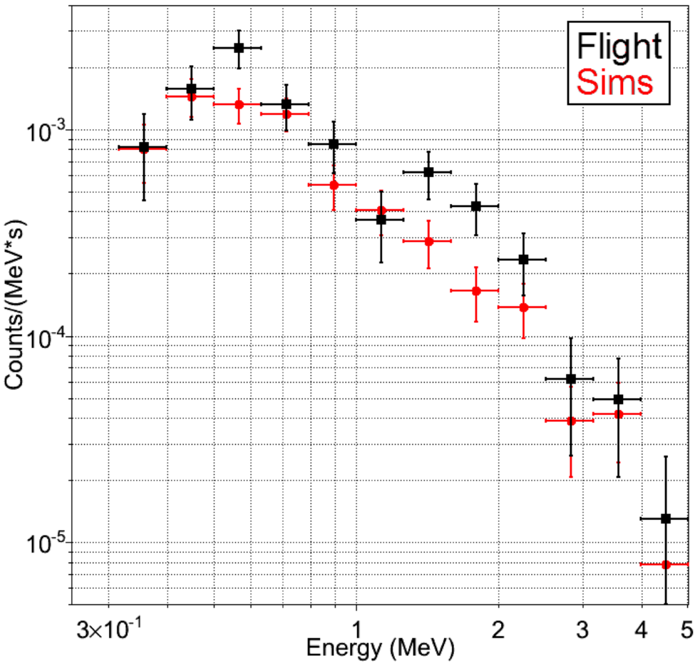


FACTEL Flight Results (2011)

Flight Corrected ToF



Flight vs Sum of Sims



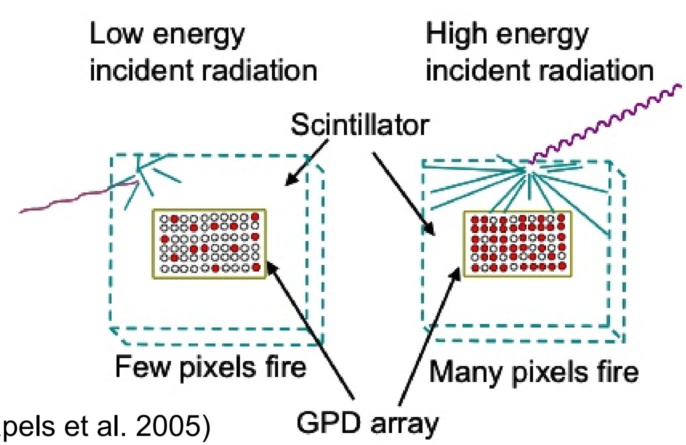
- ToF spectrum fully described by two Gaussians
- “Down” and “Up” gammas cleanly separated
- FWHM ~ 1.2 ns

- Downward moving gamma spectrum agrees with Geant4 simulations

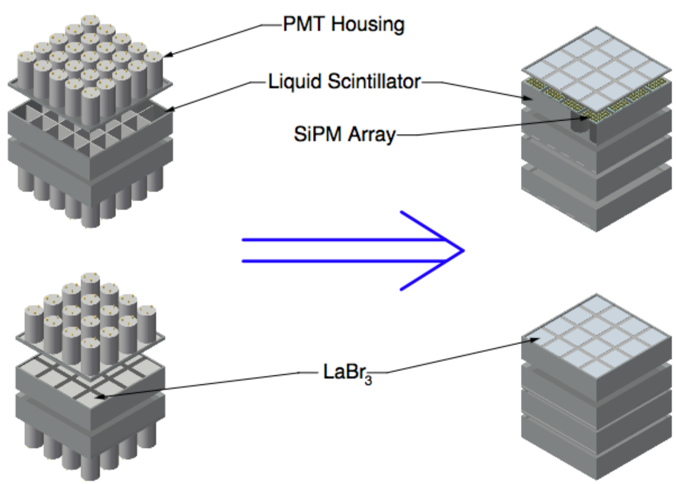
Julien, M., et al., 2012 IEEE NSS Conference Record, 1893

The Silicon Photomultiplier (SiPM)

- Scintillator detectors limited by size, mass, and power of readout
- A SiPM (aka SSPM, MPPC) is a summed array of tiny (~50 μm) silicon APDs reverse-biased slightly above breakdown voltage in *limited Geiger mode*; recovers in 10s of ns
- SiPMs are compact, light, robust, low power, LV (30 - 70 V), and have gain (10^5 - 10^6), timing (~1 ns rise time), and effective quantum efficiency (20% - 30%) equivalent to PMTs
- ***Replacing PMTs with SiPMs in a Compton telescope would eliminate passive material, reduce mass, and allow closer packing***

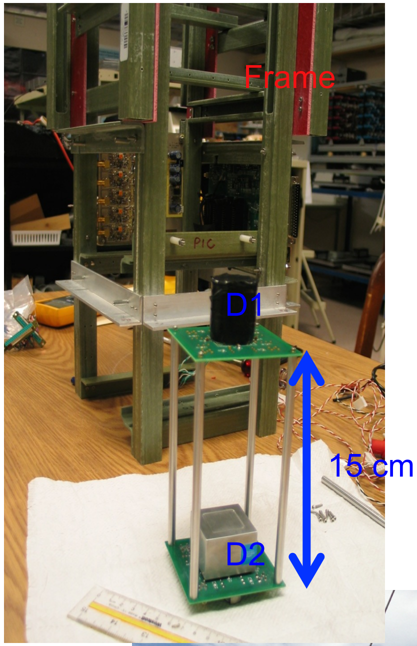


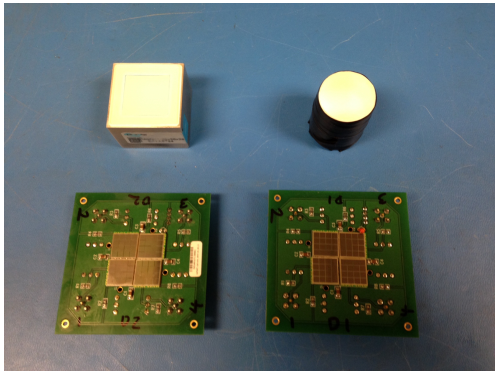
(Stapels et al. 2005)



SolCompT Experiment

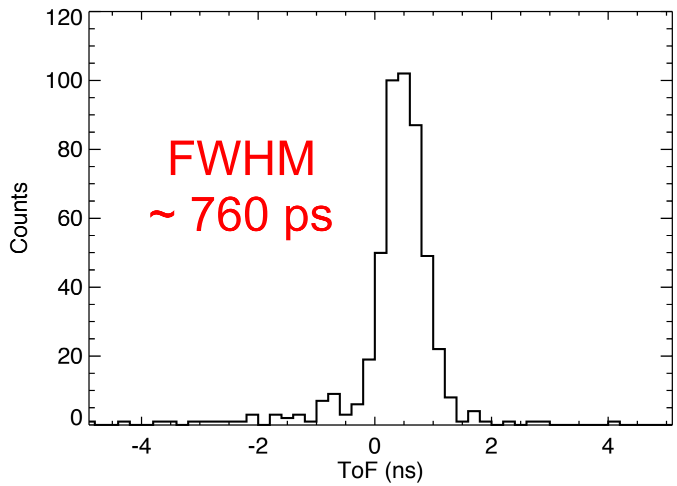
- 2-element Compton telescope: D1 is 1-inch stilbene, D2 is 26 mm × 26 mm × 26 mm $LaBr_3$
- Both read out using 2 × 2 array of Hamamatsu S11828-3344 MPPCs with transformer FEE for low input impedance
- Payload used hardware (pressure vessel, heaters, readout electronics, and PC-104 computer) flown in 2011 as part of the FACTEL payload
- Tagged ^{60}Co source (~240 nCi) to monitor gain and energy resolution

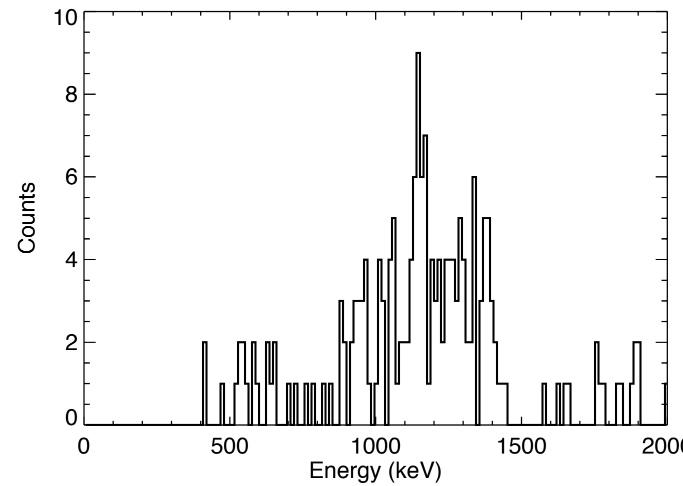




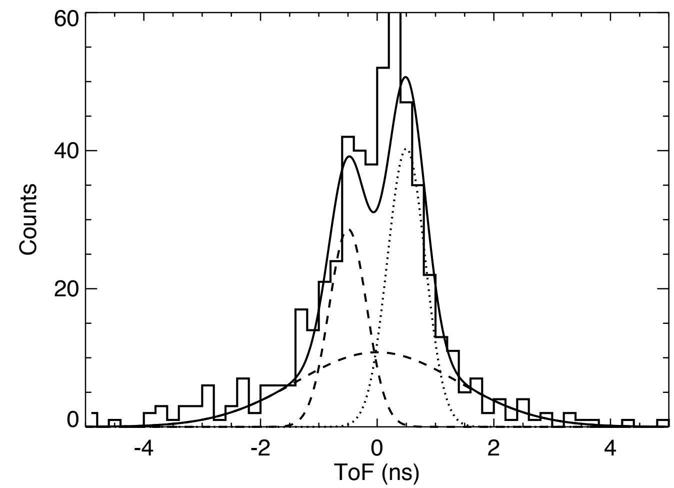
SolCompT Flight Results (2014)

Although only had 3.5 hours at float, tagged events ^{60}Co show good ToF and energy spectra:



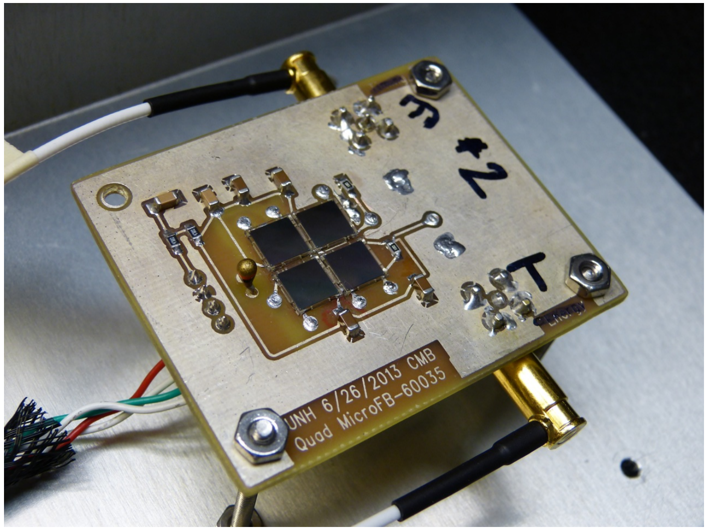


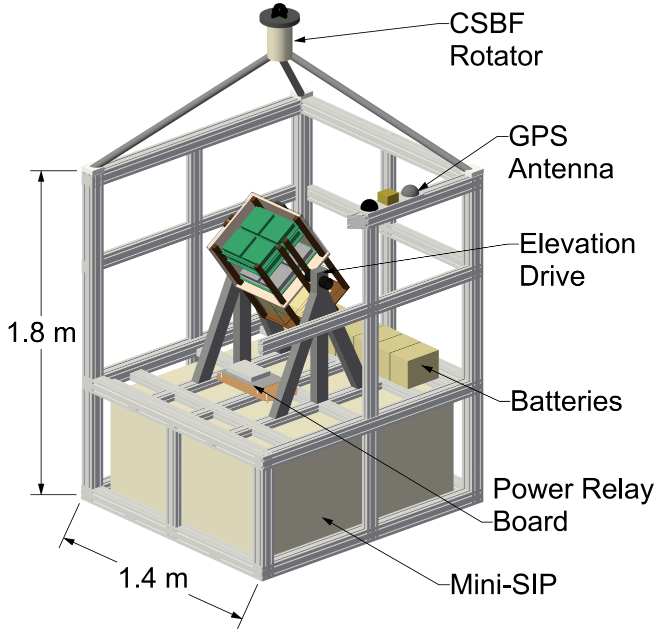
Untagged events harder to interpret due to small spacing and surrounding material – but still see up vs. down on top of broad continuum:



The ASCOT Balloon Project

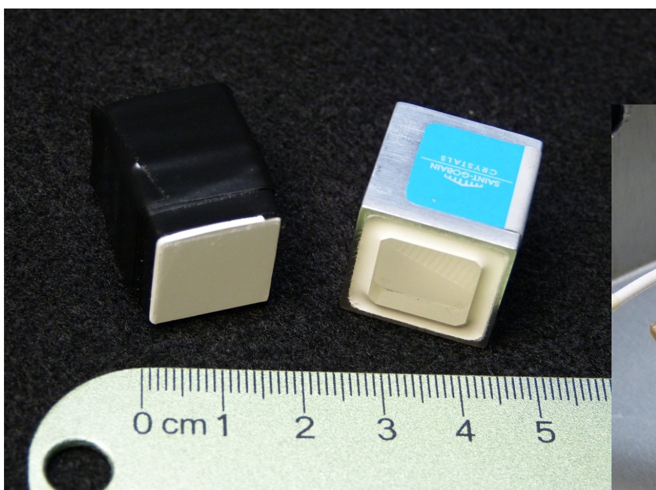
- We are beginning a program to fly a larger scintillator-based Compton telescope with SiPM readouts on a balloon and observe the Crab in a 1-day flight
- D1 will be p-terphenyl organic scintillator; D2 will be $CeBr_3$ (due to difficulties with Saint-Gobain, also lower internal background)
- Will use the SensL MicroFC-60035-SMT 6 mm × 6 mm SiPM – has "fast" output, good for ToF

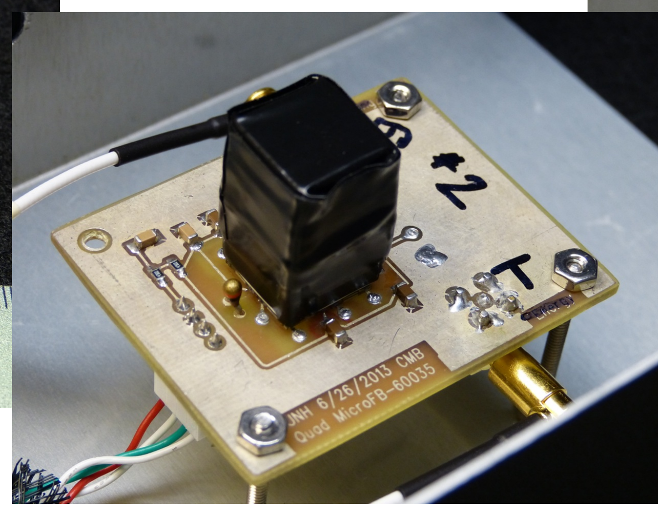


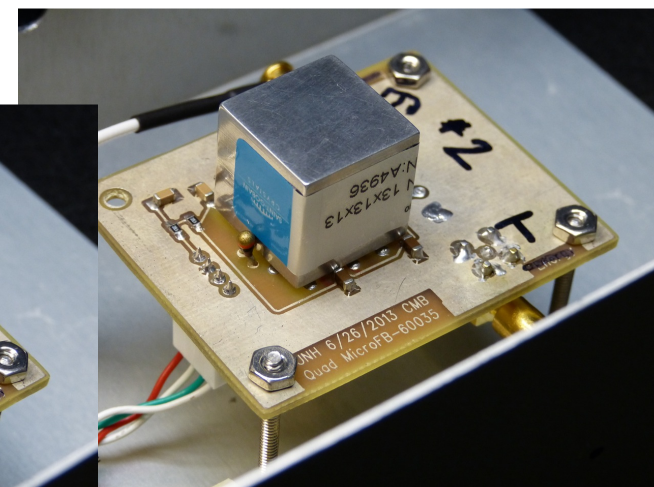


Laboratory Measurements

- Proof-of-concept lab measurements use two 2 × 2 SensL SiPM arrays (fast output)
- Two 15 × 15 × 25 mm^3 p-terphenyl crystals, wrapped in white Teflon tape, and a 13 × 13 × 13 mm^3 $LaBr_3$ crystal
- Custom bias voltage (31 V) supply that provides offset voltage (~22 mV/ºC) based on the resistance of the thermistor bead

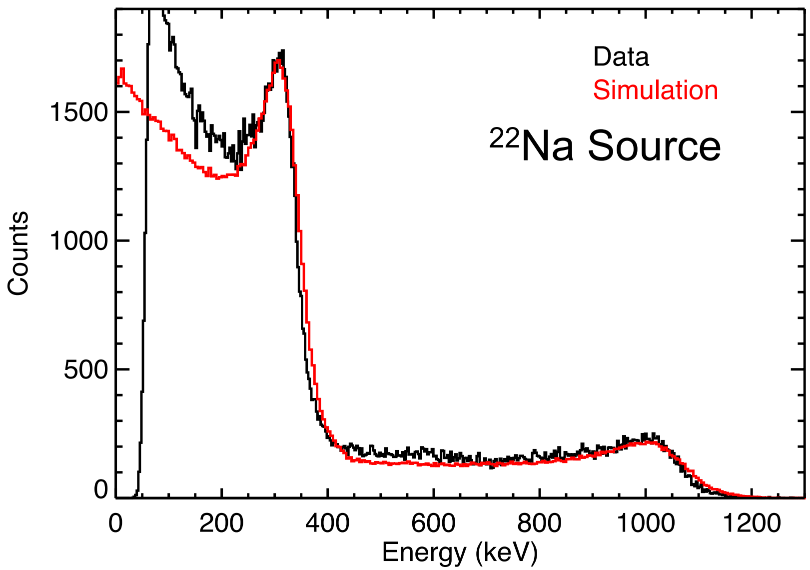


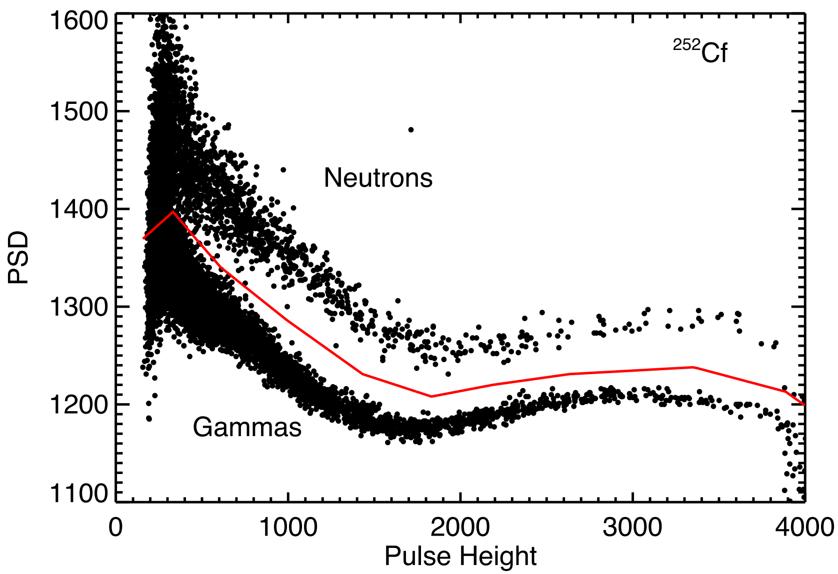




SiPM/p-terphenyl Response

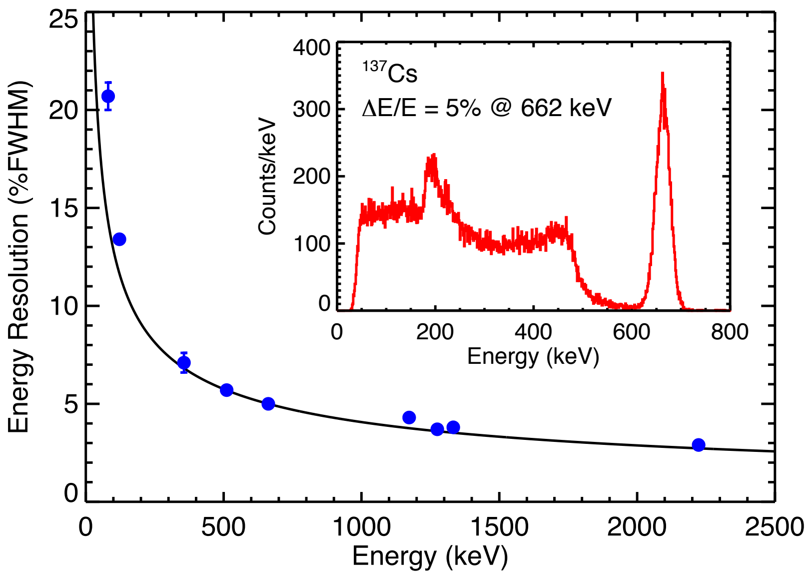
- P-terphenyl energy response determined by gamma measurements combined with simulations
- PSD response determined with ^{252}Cf fission source

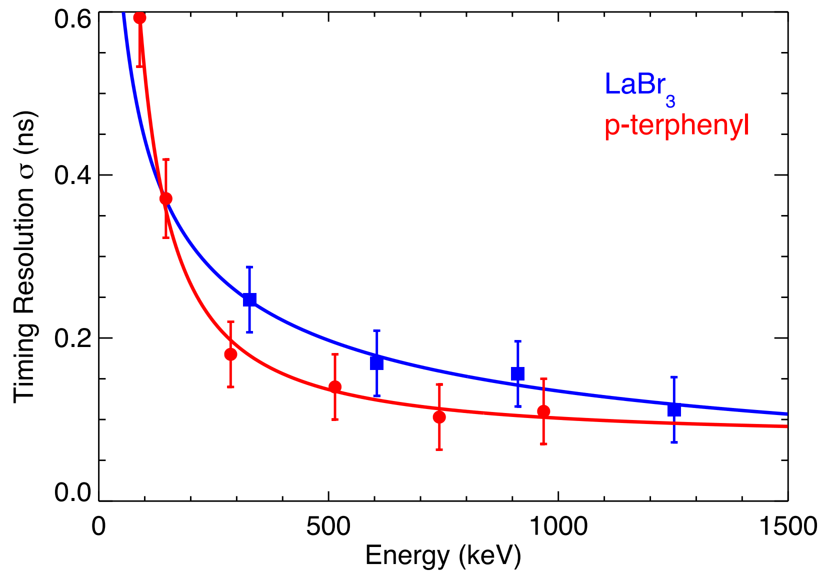




$LaBr_3$ Energy, Timing Response

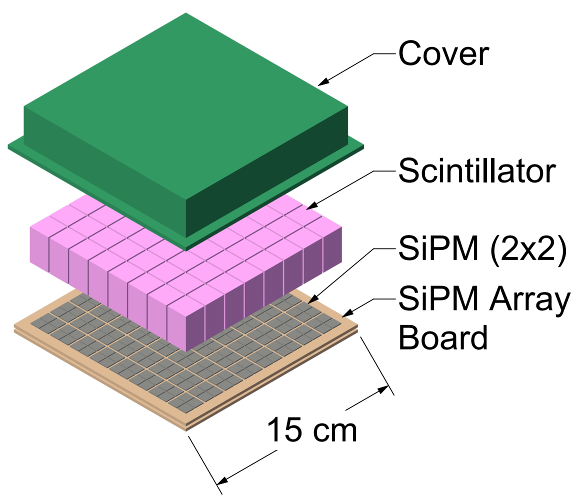
- $LaBr_3$ calibrated up to 2.2 MeV with gamma source
- ToF calibrated using coincident gamma rays from ^{60}Co source: first two p-terphenyls, then p-terphenyl/$LaBr_3$
- After correcting for pulse-height-dependent walk, derive timing resolution contribution of single elements

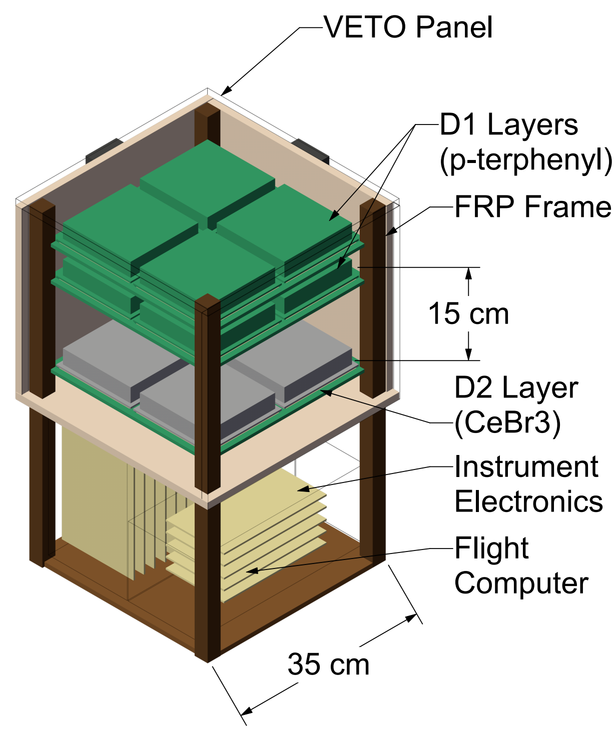




ASCOT Balloon Instrument

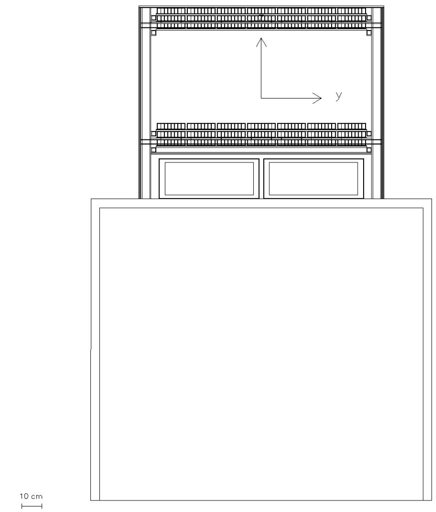
- Instrument concept: basic “module” with 8 × 8 scintillator array optically coupled to a 8 × 8 SiPM array
- Each scintillator 15 × 15 × 25 mm^3
- Each scintillator read out by 2 × 2 SiPM array (same as lab tests)
- Detector layers each 2 × 2 array of modules
- Two D1 layers, one D2 layer (cost)
- Estimate ~4σ Crab detection



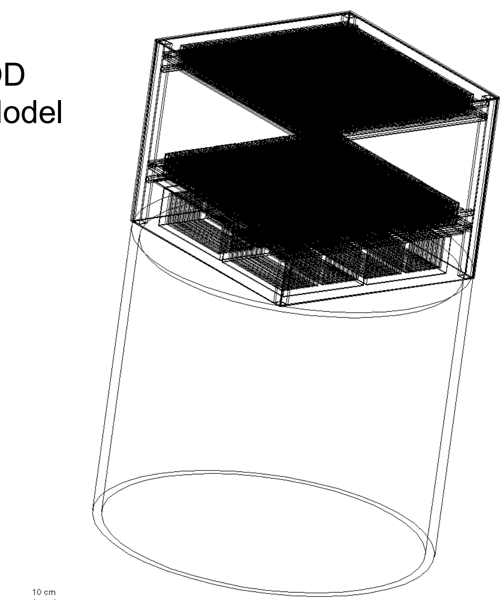


Simulation of Potential Explorer Mission

- Explorer-sized instrument concept: 7 × 7 array of modules forms a “layer”
- Three D1 layers and three D2 layers, 50 cm separation
- Assume FRP frame (as in FACTEL), plastic ACS
- Estimate 120 × 120 × 100 cm^3 instrument, ~1000 kg payload
- Simulate response and background with MGGPOD – assume radiation inputs from Advanced Compton Telescope Concept Study for 5° inclination, 550 km LEO
- Use measured detector response

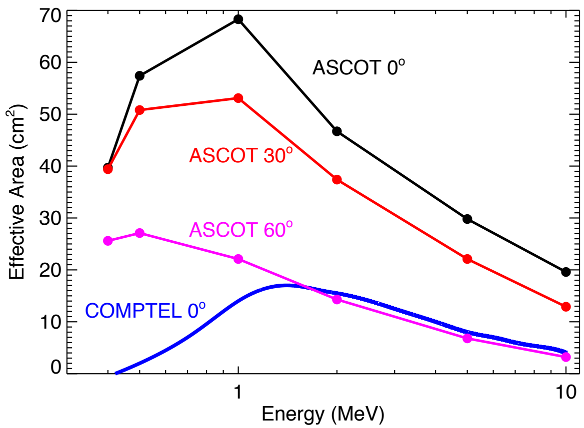


MGGPOD
Payload Model

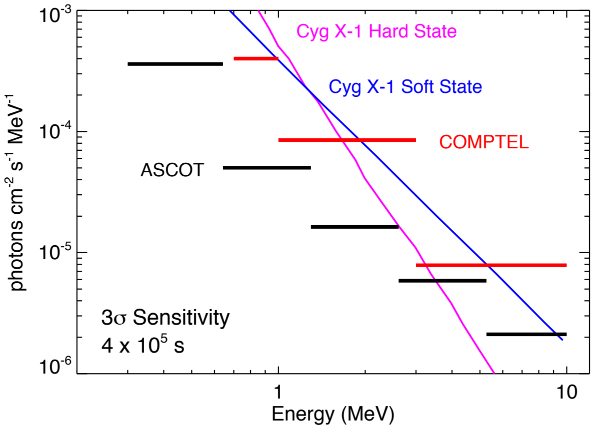


Simulated Compton Telescope Performance

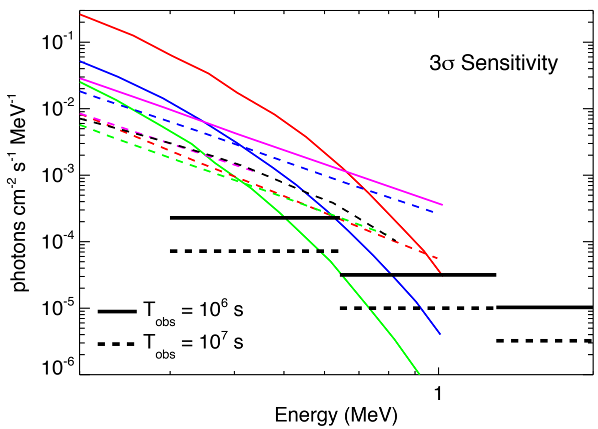
Simulations indicate that an Explorer-sized Compton telescope using this technology would greatly improve on the performance of COMPTEL:



Much greater effective area than COMPTEL, especially below 1 MeV



~8 times better on-axis continuum sensitivity around 1 MeV for 2-week observation (compare to COMPTEL Cyg X-1 spectrum)



Instrument could study MeV spectra of multiple Galactic black holes (spectra from OSSE)